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# ANALYSIS OF INVESTMENT CASTING OF GOLD AND THE PRODUCTIVITY IMPROVEMENT

**HARDIK U. SONI, VINAY K. THUTE**

Department of mechanical engineering, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, Maharashtra, India

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**Abstract:** The paper is focused on the work done on project which was initiated to analyze the investment casting process for metal Gold which was capable to enhance the quality and productivity of the casting product and also to reduce the loss of gold during investment casting process. We made the use of vacuum assisted casting machine for the experimentation purpose and the project work was undertaken at S.B Casting Works which is located at Rajkot.

**Keywords:** Investment Casting, Vacuum.

**Corresponding Author: MR. HARDIK U. SONI**

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**INTRODUCTION**

Gold is a widely used metal particularly in a jewellery manufacturing industry and investment casting process is mostly prefered technique for the production of gold jewellery. The technique of investment casting is one of the oldest and advanced of metallurgical arts and at present time, jewellery casting is passing through an era of considerable change [1]. Investment die casting process is widely used process with regards to jewellery manufacturing. Jewellery manufacturing accounts for about 80 percent of the gold that is fabricated each year. The term jewellery as used in this section refers to “karat jewellery”. The term karat refers to the purity but purity expressed in terms of $24^{th}$, rather than parts per thousand, thus 24 karat gold is 1000 fine [4]. Futher the purity of gold also varies from country to country,region to region and so the the karat are futher divided as 23k,22k,21k,20k,18k,14k,10k,9k,8k where k refers karat. In this karat category [23, 22,21k] shows the richest colour and luster and are most resistant to corrosion. They are, however low in strength, hardness, and abrasion resistance and consequently are used primarly in rather massive type of jewellery. At the other side [10,9,8] karat gold lacks the rich color and luster of gold and these are much oftenly used. The intermediate yellow karat 18 and 14 karat gold is much widely used in almost all ypes jewellery works but most proberly with regards to diamond jewellery because of their excellent mechanical properties and good corrosion resistance. The present work is done regards to 22karat gold. Nowadays to sustain in market one has to strive for maximum output with minimum loss and within stipulated period of time and as more the productivity of the company more is the profit. The need of analysis of investment casting process for gold is to increase the productivity by reducing the loss of gold occurred during casting process. And for this analysis is the best tool for completing the required task. The present work addresses to the solution for the failure, defect and loss which occurs during casting process. On account of this the detail study of the investment casting is carried out along with tracing of out the areas where defects are been generated. Main causes of the defect are researched and best suited solution for the problem is given in the paper.

II. DETAILED INVESTMENT CASTING PROCESS

The starting point for the production of jewelry casting is to first design the master pattern of the part which is to be casted. The master pattern can be of any metal such as silver, copper. From the pattern the negative die is to be made for the production of expendable patterns. For this, the most usual procedure is to vulcanize a solid block of rubber around the master using the heat and pressure, subsequently parting the die and removing it by using surgical scaples. Two part dies made in this way can reproduce complex designs with heavy undercuts by low

pressure injection of molten wax by making use of wax injector machine. Wax injector machine uses injection wax known as beads which provides minimal shrinkage and excellent flow. After the wax pattern is formed than comes the formation of the wax tree. Wax pattern are set up in large or small numbers depending on production requirement and casting machine capacity. Various technique are been followed for pattern set up but the most common technique used for quantity production is to attach the pattern radially. Once the pattern is set up it is placed in the flask in which the further investment added. The investment (powder) is based on the combination of plaster and silica which are mixed with water. The investment plays important role in providing lustrous finish to the casting. The mixing of powder to water ratio is 100gm:40ml for regular casting works. The flask is than subjected to the casting furnance. In this step the casting flask is been heated up to 750 to 800 degree Celsius in the furnace which results in melting of wax and formation of the cavity of the desired shape of the object takes place. The process is also called as burnout process. After completing the burnout process the flask is then inserted to vacuum casting machine where gold in molten form is poured into the flask via small opening in presence of vacuum. The vacuum pressure should about6to7bars.Then, finally comes the process of deflasking of the raw casting tree from the flask using water quenching process. And in this way the raw casting of the object is obtained and further this raw casting tree is moved to polishing technique.

## III.DETAILED OF VACUUM CASTING MACHINE

The principal of vacuum assisted casting machine is that mould is placed in the heat resisting gasket on a flat table over a hole connected to a vacuum pump and vacuum was applied to the base of the mould while the molten metal was poured. The low pressure in the mould cavity caused atmospheric pressure to force the metal into the mould, filling being assisted by reducing of the cushion effect of the air in the mould cavity. The process is also called “vacuum assisted casting”. The perforated moulding flask is used which is fitted with a heavy flange on the upper or molten metal entry end. The machine consist of the cylindrical casting chamber, large enough to accommodate the largest mould used ,and which has an open top with corresponding to the flange of the flask. The casting chamber is fitted inside a vacuum chamber of large volume and is isolated from it by a large diameter quick opening valve. The vacuum chamber is provided with a simple gauge and is evacuated by a rotary pump. The metal is melted independently in an electrical melting machine and when casting is to be carried out, the vacuum chamber is pumped out with the valve closed and the hot investment mould is seated on the flange of the casting chamber with a heat resisting gasket interposed between the flanges. The molten metal is been poured into the mould cavity by hand the vacuum valve

being opened simultaneously before the metal stream is being poured into the mould cavity. The machine provides excellent service for high volume of production for small jewellery casting and also large size casting which are too heavy for production on centrifugal casting machines.

## IV. DETAILED VACUUM CASTING PROCESS

### **A.** DESIGN THE MASTER PATTERN

The first step is to design the master pattern of the component to be casted. This can be accomplished in either two ways in which one is by hand made pattern designed by the skilled workers who are expertise in jewellery designing. The pattern designed by hand made is of mainly metal silver and copper. The second way to design pattern is by using Cad/Cam software in which the pattern is first designed in cad jewellery software and then the file is transferred to Cam system for pattern generation. The pattern generated using this technique is of wax material.

### B. DESIGN OF THE MASTER DIE

The second step is to generate the master die of the pattern which is generated either by hand made or by using Cad/Cam technique. The formation of the master die can be done in either two ways depending upon the type of the master pattern generated i.e. if the master pattern is of metal the die can be generated using the silicon molding rubber with the help of vulcanizer machine and if the master pattern is wax than the formation of the die is carried out using liquid rubber molding solution. The die is further divided in two equivalent parts using mould cutting blades so that the multiple wax patter can be generated out of it.

### C. GENERATION OF THE WAX PATTERN

The third step is to generate the multiple wax patterns with the help of master die. This can be accomplished by using wax injection machine. The wax injection machine makes use of injection wax which is inserted into the injection machine and further the patters are generated when the injection wax in molten form is transferred to the master die via small opening which is designed in the die.

### D. FORMATION OF THE WAX TREE

Once the multiple wax patterns are generated then the formation of the wax tree is carried out. In this step each wax pattern generated is mounted into the wax stem this is done with the help

of electric soldering machine. The mounting of the wax pattern is done in such a way that each wax pattern is at equidistant from each other and is arranged in radial manner.

E. MOUNTING OF THE WAX TREE AT THE RUBBER SPRUCE BASE

After the formation of the wax tree is completed than it is mounted onto the rubber spruce base which done with the help of electric soldering machine and further this spruce base is mounted along with perforated casting flask.

F. PREPARATION OF INVESTMENT MIXTURE FOR CASTING

In this step we need to prepare the powder investment mixture in which we make use of investment powder which shows the properties such as permeability, lustrous finish in casting and rapid burnout. For proper mixture of investment powder and water the ratio of powder to water is 100gm: 40ml for regular casting. After powder preparation it is poured into flask.

**Fig: 1 Investment Powder**

G. LOADING THE CASTING FLASK INTO FURNANCE

This process is also called as burnout process. After the investment has once set in the perforated flask than this flask is further transferred to the heating furnace in which the flask is heated up to 750to 850 degree Celsius and due to this heat treatment the wax tree mounted into the flask turns to molten state and this results in formation of the cavity of the desired casting design. The burnout process can be of 4hr, 5hr, and 6hr depending upon the type of investment powder used.

**Fig: 2 Casting Furnaces**

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H. POURING OF METAL INTO THE CASTING FLASK

In this step the metal to be poured into the flask is first heated up to the melting point using electric melting furnace. Once the melting point of the metal is achieved then the flask is mounted into the vacuum casting machine and the molten metal is simply poured into the flask by hand, the vacuum valve is being opened simultaneously before the metal stream strikes the mould surface. After the metal being poured into the flask the flask is let to cool at room temperature.


**Fig: - 3 Metal Pouring**

I .DEFLASKING THE CASTING FLASK

The flask should be cooled at room temperature before deflasking and this may be accomplished by water quenching technique. Once the flask has cooled below red hot, provided that the metal can resist to the quenching the casting can be taken off and can further be carried out and after this we obtained raw casted tree.

V. PROBLEM IDENTIFICATION

The investment casting process needs to improve in productivity and reduce the failure in casting and loss of gold in the casting process. After the survey of the complete manufacturing process it is noted that failure of the casting components occurred due to following factors and the parameters where improvement can be establish.

1) Design problem because of manual master pattern.

2) Problem in master die making.

3) Improper filling of.

4) Inaccurate mixture of investment powder.

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5) Inaccurate wax to gold ratio.

6) Additive elements- use of alloy.

7) Melting technique for gold.

8) Polishing technique for gold.

The existing problem can be solved out by making advancement in each step of investment casting process and to develop an alloy which will enhanced the productivity and will reduce the loss of gold occurred.

VI. SOLUTION TO THE EXISTING PROBLEM

TO DEVELOP THE MASTER PATTER WITH THE USE OF CAD/CAM TECHNIQUE

In this step the master pattern is designed with the help of Cad/Cam jewelry software. The Cad/Cam software offers various features such as revolution, hole, loft, sweep, fillet, chamfer, shell, spiral, helix etc. in this the design to be generated is first done by the cad designer using software and once the design is completed than the file is transferred to cam process. The Cad/Cam software generally used for jewelry design is Jewl-Cad which is the primary version, Rahino Ceros jewl design is secondary and besides these there are various software available for designing. The master pattern designed by this technique is of wax material which is quite fine quality, less in weight. In the present work we made use of Cad/Cam technique. The figure shows design generated using Cad/Cam technique.

**Fig; - 4 Ring Pattern**

TO DEVELOP THE MASTER DIE WITH THE HELP OF LIQUID DIE TECHNIQUE

The use of liquid cast makes the mould stronger, tougher, and long lasting and of better surface finish. The liquid cast is easier to mix, easier to vacuum and easier to pour and the pattern drawn out of this liquid die is of less weight as compared to silicon rubber die. The liquid die

makes use of liquid rubber frames in which the master pattern can be mounted at its base and with the help of clamping arrangements it can be closed so that the liquid can be easily poured into it. The mould made out of this technique can be of thickness 19mm, 25mm, 32mm, and 38mm.

FORMATION OF THE WAX TREE

The wax pattern generated with the help of master die is now to be mounted into wax stem for further casting process. The arrangement done was as such the wax patterns were mounted in Spiral manner and an equal distance was maintained between two wax patterns which resulted in uniform meshing of investment powder and the wax patterns, the formation of cavity was in excellent and failure of the casting components was reduced.

**Fig: - 5 Spiral Arrangements**

PREPARATION OF INVESTMENT POWDER MIXTURE

The quality of the investment powder used plays an important role in casting and a good investment casting powder shows following properties good permeability, super smooth finish, rapid quench, metal acceptance capacity and not only the quality but the cycle time in which the powder mixture should be prepared and poured into the casting flask plays an important role in enhancing the quality and quantity of the casting component produced and so the following time cycle was formulated

**Table I: Specification of the Time Cycle**

| Time in minutes | Mixing instructions |
|---|---|
| **0 to4** | Add powder to water with ratio (100gm : 40ml) |
| **0 to 1** | Vacuum the investment powder bowl |
| **0 to 1** | Pour the investment into the casting flask |
| **0 to 2** | Vacuum the casting flask |
| **0 to 1** | Top up the flask with investment power |

Once the investment powder is being poured into the casting flask then the flask is left still for 45 minutes so that the powder mixture gets fix into the flask. By following this time bound we obtained uniform distribution of the powder and the wax tree mounted inside casting flask and this resulted in reducing the failure.

MIXTURE OF WAX TO GOLD RATIO

The amount of gold required in order to cast a particular wax tree depends the weight of the wax tree which in turn depends upon the specific gravity of the of the gold. The specific gravity of 24 karat gold is found to be as 19.32 but the casting cannot be carried out with 24 karat gold so we need to convert it into 22 karat gold whose specific gravity is found to as 17.76. So the amount of gold required to cast a particular wax tree can be estimated using the value 17.76 as the multiplication factor. The wax to gold ratio was found to be as [1: 17.76] the ratio proved to be beneficial in calculating the exact amount of gold required which in turn reduces the failure due to incorrect mixture of gold to wax ratio.

ADDITIVE ELEMENTS – USE OF ALLOYS

We know that the in order to carry out casting process the pure form of gold i.e. 24 karat cannot be used and so we need to change this pure form of gold in 22 karat gold. This can be converted with the help of relationship of fine. And so we can convert the 24 karat gold to 22 karat by- 22/24 = 0.916gm. This states that we need to add 9.16gm of alloy per hundred gram of pure gold and this addition will turn the pure gold to 22 karat which is suitable for casting. The word alloy is given to the mixture of four different metals which are silver, copper, Zink and cadmium and this are melted together in appropriate ratio in which the ratio of copper is highest about 75 to 80 %, silver 15 to 20% and the rest is occupied by Zink and cadmium. For this purpose we carried out the experimentation using our different alloy A, B, C and D and it was found that the alloy D showed better results as compared to rest of alloys. The results showed that the casting produced was of good quality, improved color and it also improved the productivity by reducing the loss occurred during process. The following table II states the details about the alloys and table III shows the loss of gold occurred by using each alloys.

**Table II: Distribution of Alloys [%]**

| ALLOYS | COPPER | SILVER | ZINK | Cadmium |
|---|---|---|---|---|
| A | 76.84 | 07.33 | 0.00 | 0.00 |
| B | 60.15 | 22.23 | 3.95 | 5.86 |
| C | 80.55 | 17.08 | 0.76 | 0.10 |

| | | | | |
|---|---|---|---|---|
| | - | | | |
| **D** | 79.88 | 17.52 | 1.103 | 0.047 |

**Table III: All units in GM**

| Alloy | Actual weight before casting | Actual weight after casting | Manufacturing cost | Loss of gold | Loss Per 1kg |
|---|---|---|---|---|---|
| **A** | 350 | 344.750 | 5.250 | 2.110 | 6.01 |
| **B** | 175 | 172.37 | 2.625 | 0.945 | 5.433 |
| **C** | 100 | 98.500 | 1.500 | 0.510 | 5.100 |
| **D** | 246 | 242.310 | 3.69 | 1.107 | 4.480 |

MELTING TECHNIQUE FOR THE GOLD

In the melting technique the analysis was carried out with regards to melting the gold in an open furnace and in electric melting machine and results shows that the gold which is being melted in open furnace loses its weight more as compared to electric melting furnace. The analysis also shows that the gold melted in small batch size loses its weight more as compared to larger batch size (quantity). The table IV shows the comparison of the gold melted in each open furnace and that in electric melting machine and in the present work the melting of gold was replaced by electric furnace.

**Table IV: Loss of Metal in Melting**

| Actual weight before melting [GM] | Weight After melting [open furnace] | Weight After melting [electric furnace] |
|---|---|---|
| **350** | 349.550 -(0.450) | 349.850 -(0.150) |
| **175** | 174.810-(0.190) | 174.920-(0.080) |
| **100** | 099.850-(0.150) | 099.950-(0.050) |

**Fig: - 6 Electric furnace**

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POLISHING TECHNIQUE FOR THE GOLD

The basic polishing technique which is generally followed is shouldering followed by filling, buffing, stone studding and finally polish. Now in order to enhance the quality of the casting components the change was made in the polishing technique and this change not only improved the quality but also improved productivity by reducing the time involved in polishing process.

SHOULDERING ⇨ GRINDING ⇨ BUFFING ⇦

⇨ BLACK BUF ⇨ RED BUFF ⇨ STONE STUDDING – MAGNETC CLEANER STEAM CLEANE ⇨

**VII. RESULTS AND DISCUSSION**

While it is true that investment casting has been the backbone of the development of the jewellery casting to the present level of efficiency and after the study/analysis of complete investment casting process the areas were identified where improvement was possible and the areas found were designing of the master pattern , designing of the master die, design of the wax tree, factor of wax to gold ratio, investment powder technique, improvement in use of additive elements, melting technique of gold, polishing method and by improving these areas the failure and the loss has been reduced. The results are been discussed in the table V.

**Table V: Results**

| Sr No. | Parameters | Before | After |
|---|---|---|---|
| 1 | Design of Master Pattern | 2 Days | 1Day |
| 2 | Design of Master Die | 1Day | 4 to 5 Hours |
| 3 | Design of wax tree | Rejection 5% | Rejection 2 to 3 % |
| 4 | Investment powder [cavity formation] | Moderate | Good |
| 5 | Alloy [loss of gold per kg in [GM] | 5* | 3* |
| 6 | Melting furnace[loss of gold per kg in [GM] | 1.500 | 0.550 |
| 7 | Polishing technique | Moderate finish | Excellent finish |

Casting machine in future should have flexibility allowing large or relatively small melts to be made under vacuum. Pouring should be by means of smooth entry of metal stream into the mould and the necessary pressure on the metal should be as uniform throughout the mould and human enter fence should be eliminated. Also some advancement is needed to be incorporated in wax tree generation which is at present manually carried out. The results also shows that in investment casting process, use of traditional alloys gives poorer performance in comparison with the alloys containing additional elements.

## VIII. CONCLUSION

The paper describes the detailed process of investment casting process and also the advancement done in the existing casting process which in turn showed positive results by improving the failure of the casting components which in turn improved quality, productivity and the loss of gold.

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